Moscovian (Pennsylvanian) Cyclothems of Central East European Craton: Stratigraphy, Facies, Paleoecology

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Summary

The East European Craton (EEC; also known as Baltica or Russian Platform) is one of major circum-Arctic continental blocks bearing important Paleozoic hydrocarbon basins yet with poorly known Paleozoic facies patterns. The Moscovian epeiric-sea succession of the central EEC consists of meter-scale carbonate sequences or cyclothems bounded by subaerial disconformities. Three major benthic skeletal associations ("biofacies") are recognized in Moscovian cyclothems. The staffellid-syphonean biofacies is a shallow warm-water photozoan facies resembling the Permian chloroforam facies but with fewer dasyclades and more important phylloid algae. The deeper-water, high sea-level facies are classified to the bryonoderm extended biofacies which is a Late Paleozoic variety of the heterozoan to photo-heterozoan facies. The Meekella-Ortonella biofacies is established in tidal flat to shallow lagoon marginal-marine facies and is considered outside the photozoan association.

Introduction

Cyclothems are prominent, apparently glacioeustatic, meter-scale sequences widely recognized in the late Mississippian through Lower Permian sedimentary successions across the former shelves of Euramerica and elsewhere in the World. Cyclothemic pattern has been recently demonstrated for the type Moscovian sections of the central EEC (Kabanov, 2003, 2009; Kabanov, Baranova, 2007). Attempts to correlate North American and EEC Pennsylvanian cyclothem successions (Heckel et al., 2008) arose many uncertainties. The facies and paleobiotic pattern of the Moscovian sections of the EEC are markedly different from the stratified and eutrophized Midcontinent Basin but has many in common with the Pennsylvanian carbonates of the Arctic (e.g. Reid et al., 2007). This paper reports new details of the Moscovian strata from the type areas of the Moscovian stage that are not yet widely known.

Geological and paleogeographical context

The Moscovian (middle Pennsylvanian) of the central EEC is an epeiric-sea succession of shale-carbonate to pure carbonate, unevenly dolomitized strata. The character of dolomites seems to be most consistent with the reflux dolomitization model. Excluding desulphatization along the outcrop belt, this succession shows little alteration: it is almost intact tectonically and avoided hydrocarbon migration, mass transfer, and burial deeper than first hundreds of meters. During the Moscovian, the central and eastern EEC was covered by one eperic sea, over 1500 km from present-day west to east, with relatively uniform facies across. This "Moscow basin" extended over several tectonically different intracratonic subsidence areas and broadly connected to the Arcric shelf.

Materials and methods

Numerous field trips from 1994-2007 have provided detailed field logs of 26 outcrop sections of the Podolskian-Myachkovian (upper Moscovian) and few sections from the Kashirian (Lower Moscovian) and the lower Kasimovian intervals of the southern Moscow Basin, the Oka-Tsna Swell (southeastern Moscow Basin), and the western Mezen Basin. The facies interpretations are completed by microfacies data from over 1000 thin sections covering selected sections with frequency 1 - 5 th.sect./m. Paleoecological studies involved quantification of selected groups. Calcareous microfossils (primarily fusulinoids and calcareous algae) were counted at the genus and family level in thin sections (count areas ≥ 10 cm^2). Conodonts are obtained by standard dissolution technique with buffered acetic acid (data of A.S. Alekseev). Quantification of macrofossil fragments has been conducted in a Domodedovo cyclothem of three quarry sections with details available in (Kabanov et al., 2006; Kabanov, 2009). An array of instrumental methods is applied to cyclothem-capping paleosols (Kabanov et al., 2010).

Lithofacies and Stratal Patterns

The best studied Podolskian-Myachkovian succession consists of seven major meter-scale (2 – 30 m thick) cyclothems bounded by subaerial unconformities. Many unconformities are composite, showing two or more subaerial exposure surfaces divided by thin (normally < 0.3 m) shallow-marine incursive limestones (Kabanov et al., 2010). Deepening and shoaling trends within cyclothems are suggested by lithofacies and paleobiotic changes (Fig. 2; Kabanov and Baranova, 2007; Kabanov, 2009). The transgressive and falling-stage systems tracts typically are built of shallow subtidal bioclastic limestones with textures ranging from wackestones to grainstones and rudstones, rarely biostrome-forming phylloid-algal boundstones, whereas highstand systems tracts commonly consist of marly bioclastic wackestones, mudstones, and the mud-dominated units with preserved rhythmic storm bedding regarded as tempestites. Many sequences are capped by lagoonal to intertidal mudstones and grainstones of variable thickness which are subaerially altered from top. In rare cases paleosols directly truncate normal-marine shallow subtidal packstones and wackestones. Sequences (cyclothems) usually include several parasequences which are submeter- to meter-scale fining-upward units whose facies composition depends on position within cyclothems (Fig. 2). Parasequences are bounded by erosional surfaces and are commonly built of thin basal peloidal-bioclastic grainstone grading up to thicker bioclastic packstone and wackestone. The Myachkovian cyclothems are recognized in ca. 1000 km to the North in the western Mezen Basin (Kabanov and Baranova, 2007). Superposition of several orders of sea-level oscillations is evident from the levels of shoaling and ‘ephemeral’ subaerial exposure complicating the main transgressive and regressive trends. The number of cyclothems in the Vereian-Kashirian (Lower Moscovian) interval remains uncertain. However, the Yambirno section of the southern Oka-Tsna Swell exposing lower one third to one half of the Kashirian reveals seven cyclothems, which suggests duration of the entire Kashirian longer than the Podolkian-Myachkovian interval.

Paleoecology

Three major benthic skeletal associations (“biofacies”) are recognized (Fig. 1; Kabanov, 2009).

Staffellid-syphonean biofacies

This photozoan association is recognized in shallow normally clay-free carbonates deposited in oligotrophic waters. This facies is distinct by presence of fragmented and whole thalli of Udoteacean “Phylloid” green algae and persistent presence of staffellid foraminifers (genera *Reitlingerina* and *Parastaffelloides*). Micritized grains, micritic intergranular and intraskeletal cements, and peloids are common, ooids sporadic. Dasyclad algae are rare (< 0.3-0.5 fragments/cm^2), occur in shallower lithofacies. Beresellan algae are sometimes abundant. At least 5% of sand-sized carbonate particles are micritized. The skeletal benthos is variable in composition and diversity. The diversity is normally high, showing low degree of dominance. The colonial cerioid tetracorals occur sometimes in considerable quantity. The staffellid-syphonean facies correspond to the brachiopod biofacies Choristites (Kabanov et al., 2006). Bioturbation is mostly cryptic and vigorous but in shoal grainstones cross-lamination is preserved. The upright and V-shaped thalassinoid burrows are sometimes present. The staffellid-syphonean facies is generally photozoan. Some muddier textures (packstones and wackestones) comprising less than 20% photozoan markers are regarded as transitional photo-heterozoan. The staffellid-syphonean biofacies closely resembles the Early Permian chloroforam facies of the Canadian Arctic and Svalbard (Beauchamp and Desrochers, 1997) from which it is distinct by fewer dasyclad algae.

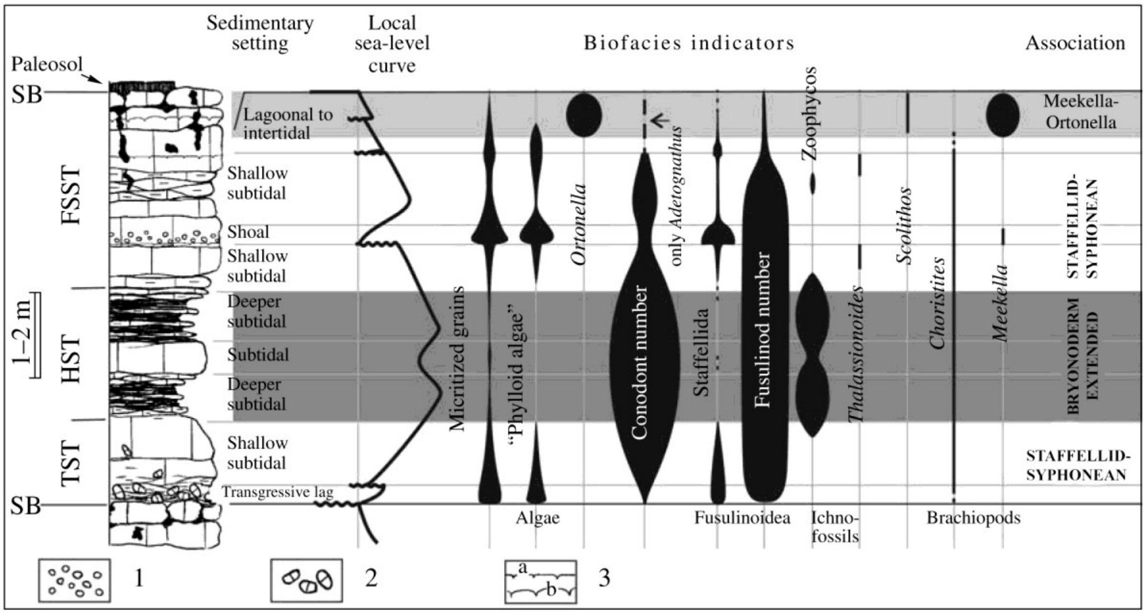

Figure 1: A synthetic Late Moscovian cyclothem of southern Moscow Region and biofacies indicators (slightly modified from Kabanov, 2009). 1 – rounded grainstones; 2 – limestone pebbles; 3 – erosional surfaces: a – planar, b – scalloped. Sequence stratigraphy: SB – sequence boundary, TST – transgressive ST, HST – highstand ST; FSST – falling-stage ST.

Bryonoderm extended biofacies

This biofacies corresponds well to the bryonoderm extended skeletal association of the Arctic Permian (Beauchamp and Desrochers, 1997; Reid et al., 2007) and occurs in highstand marly wackestones, mudstones, and limestone-clay alternations with tempestite textures. The phylloid algae, staffellids, micritized grains, peloids, and other photozoan markers are rare (1-3% of all grains larger than 0.2 mm), probably shed offshore from photozoan settings, sometimes absent. The marine cements are lacking. Bryozoans are numerous and diverse with some dominance of fenestellids. In shallower-water marly wackestone and calcimudstone facies bryozoans may also be abundant but their diversity is lower and consists only of Fenestellida (Kan, 2006). The bryonoderm extended facies are distinct by the ichnofacies Zoophycos and rich, diverse conodont assemblages (Kabanov et al., 2006; A.S. Alekseev, pers. comm.). Other characteristic features are the abundance of echinoderm sclerites, diverse brachiopods, and solitary Rugosa. The calcareous algae and alga-like Problematica with hyaline skeletons (*Donezella, Anthracoporellopsis,* Stacheinaceae, Aoujgalliaceae), are commonly present usually in lesser quantity (Fig. 5) but sometimes in greater quantity (Fig. 7) than in staffellid-syphonean facies. The beresellaceans occur sporadically. The sedentary and motile foraminifers are normally numerous and diverse but staffellids are very rare and may be allochthonous. Conodont assemblages belong to the biofacies Idiognathodus indicating the relatively shallow-water shelf with normal salinity (Kabanov et al., 2006). Another indirect evidence of relative shallowness is the insignificant quantity of siliceous sponge spicules.

Meekella-Ortonella biofacies

This biofacies is established in the intertidal herringbone-stratified grainstones, tidal-flat calcilutitic laminites, and in lagoonal calcimudstones (semi-isolated, late regressive and early transgressive lagoons). These stressed marginal-marine environments were inhabited by depleted biotic assemblages with high degree of domination. A typical feature of the herringbone grainstones is mass Ortonella. Peloids and intraclasts are also abundant. Syphonean algae are sporadic. Fusulinids are rare (< 1 test/cm^2) or absent, mostly represented by small schubertellids. Brachiopods are mostly represented by one species *Meekella eximia* Eichwald forming shell pavements and debris grainstones. Both *Meekella* and *Ortonella* are rare outside their index biofacies. Other brachiopods including *Choristites* can be found in the intertidal facies as rare allochthonous fragments. Bryozoans are represented by monotonous fenestellids (Fig. 6). Other in situ macrofossils include dome-shaped chaetetids, rare solitary tetracorals, and few other tolerant groups. Lack (or very weak) micritization of *Meekella* shells suggests that the microbial biodegredation of carbonate substrates was also depressed comparatively to the staffellid-syphonean environment. The taphonomy of the lagoonal mudstones is often transitional to that in normal-marine staffellid-syphonean facies. The lagoonal mudstones and laminites of the Domodedovo cyclothem at Akishino contain mass *Dvinella comata* Khvorova. The bioturbation is generally weak, with typical Scolithos (vertical burrows <2mm in diameter and 10-20 cm long) in the tidal-flat laminites and the thicker (up to 2 cm) upright and inclined burrows. The Meekella-Ortonella "biofacies" developed on broad tidal flats and associated lagoonal pools that mostly extend behind the wave action and water circulation regime of a normal marine basin. Attribution of the Meekella-Ortonella facies and similar tidal-flat taphonomic assemblages of other ages to the photozoan facies realm is correct taking into account abundant microbial micrites. However, other photozoan markers such as syphonean algae, symbiont-bearing foraminifers, and hermatypic metazoans are depressed or absent due to harsh life conditions with diurnal ebbs, temperature and salinity fluctuations. Therefore this "biofacies" is considered outside the photozoan realm.

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